Emerging Innovation system and Environmental Innovation: the case of mitigation techniques and CCS

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Abstract While the environmental innovations will play a key role in the transition towards a decarbonized economy, their implementation is rather difficult to be realized in advanced economies. The techniques at stake imply for some of them scale and network economies, for others changes in habits and uses, with important technical and economic uncertainties. Developing countries can benefit as latecomers from these innovations without incurring their development costs, but they are reluctant to move towards a more decarbonized economic model if this evolution should reduce their growth and limit their development. From this point of view, mitigation techinques, especially Carbon Capture and Storage techniques, from fossil fuels (CCS) or bioenergy (BCCS) appear to be a promising way to reach stringent greenhouse gas reduction targets. They allow preserve the use of fossil fuels during a transition period towards a more decarbonized energy mix. These techniques are nevertheless submitted to the evolution of mitigation costs, to the regulatory uncertainty and to their social acceptability. Their adoption by developing countries depends moreover crucially on the regulatory framework for avoided carbon emission, and of the availability of a financial support from more advanced countries.

Key Words : Environmental Economics, Innovation Economics, Energy Economics, Carbon Capture and Storage (CCS), Carbon Capture and Storage from Biomass (BCCS)

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It is rather usual to assert that environmental innovation will play a key role on the way to a more decarbonized growth, for developed as for developing countries. Nevertheless, these Innovations involve environmental and knowledge externalities which make them difficult to implement. As some of them require scale and network economies, they are highly path-dependant. Their adoption may need some change in the users (consumers and producers) practices, and is moreover supposed to bring about learning effects that are difficult to measure and forecast. Lastly, they are also bound to major technical, economic and regulatory uncertainties.

If developing countries are subject to most of these pitfalls in implementing environmental innovations, their position of latecomers allows also them to benefit from the experience of more advanced countries, a situation which has been studied in most of the literature on the catch up process. The aim of this paper is to address the question of the availability of environmental innovations in both advanced and developing countries, with a special focus on a particular mitigation technique, Carbon Capture and Storage. It will begin with a survey on environmental innovation, and more precisely in energy techniques. If innovation process is now more oriented to environment concerns, it is largely due to public policies which has to correct both environmental and knowledge externalities (Kemp (2011). In this field mitigation techniques are an important stake, as they may help the energy sector to reach its greenhouse gas reduction targets. We will study especially a controversial mitigation technique, the Carbon Capture and Storage techniques, from fossil fuels (CCS) or biomass (BCCS) energies. CCS and BCCS techniques are generaly considered as essential in order to realize the green house gas reduction target at the 2050 horizon (IPCC, 2005), (IEA, 2008). These techniques are bound to most of the limits of energy techniques, and moreover to the price of avoided carbon, to regulation uncertainty, and to their social acceptability. These techniques, once developed in industrial countries, should then be implemented in developing countries on a large scale. The paper will address the viability of the CCS as a new innovation system, the implementation of which requires strong incentives and stringent regulatory schemes. As developing countries are generally adopting an energy mix using fossil fuels on a large scale, especially on coal which is a highly greenhouse gas emission fuel, CCS will become an important stake for them. The paper will address more generally the question of the ability of national innovation systems to support and promote more friendly-environmental techniques[2]. On this last point the paper will give some results obtained on the evaluation of a BCCS project developed in the French Region Centre.

I Environmental Economics and Innovation: some stylized facts

Considered for a long time as belonging to different fields, environmental and innovation economics are by now converging in research works devoted to the economics of global warming, and to the measures required to set up coherent and credible policies leading to a decarbonized growth (Kemp (2011)[3].

Environmental and Innovation Policies are sharing a common characteristics, which is the existence of externalities, positive for the first, and negative for the second. Environmental Innovation combines these two externalities: while they are benefiting to the whole population, theirs costs are supported by private investors who have few incentives to adopt them, although some public action will help to implement them. This public action has a double role to play: it is necessary to correct the environmental externality, and to boost the innovation in order to improve the knowledge externalities. (Pop, Newell et Jaffe, 2009). For example, in the energy field, if the spontaneous market evolution had lead to a rise in the energy price, which explained for a quarter to an half of the energy efficiency gains, (Newell,R. Jaffe A., Stavins R (1999) , Gillingham K., Newell R. et Palmer K. (2009)), public action had played a key role in this field. The large observed disparities in the energy efficiency between countries can be explained for a main part by the dramatic disparities existing in taxation and regulatory schemes at the international level.

I.1 Is the green innovation machine working?

[2] This paper has benefit of the support of Region Centre CPER BCCS Artenay Project, of the LABEX VOLTAIRE Project, and of the French National Research Agency (ANR) Project DISSOLVED.

[3] Lot of highly documented reports have been recently published in this field, like the Von Weizacker Factor Five report (2009), the Recipe Report (2010), the Pro-Inno report (Arundel and alii, 2011), and the EIB Bruegel report (Kolev and alii, 2012)

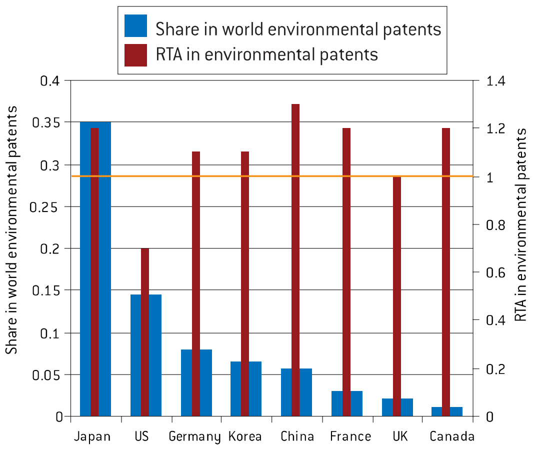
It is not surprising to state that in front of such a double market failure, innovation spendings have been during a long time very lightly turned to environmental technologies (Aghion, Veugelers, Serre, 2009). For example in 2005 no more than 2,15% of the patents declared to the international Patent organization have been in the field of environmental technologies, with the Japan as a leader which produces 35% ot these patents of its own, against 15% for the USA (table 1). An index of relative technological advantage in environmental patents (RTA) has been build up by the World International Patent Organization (WIPO), which compares the share in environmental patents to the country share in world patents. While Japan, China, France, Canada, Germany and Korea get a high RTA, it is not the case of the USA, which obtains a low score in this field. (figure 1). One sector which suffers an underinvestment in R&D is the electricity production and distribution (Table 2): despite their heavy contribution to the green house gas emission, the Electricity Generation and Distribution (EGD) R&D spendings are surprisingly weak. Their share in World RD is below 1%, and moreover it decreased in the last years, from 0,9% in 1990-95 to 0,5% in 2000-04, for a sector which weights for 2,2% of the Added Value of the same number of firms.

Table 1: Environmental technology patenting

	Share of technology 2003-05	Av. annual growth rate 1995-2005
All tech	100%	12.1%
Renewables	0.42%	15.8%
Auto-pollution control	0.85%	12.9%
Fuel cells	0.6%	24.6%
Nuclear	0.45%	5.8%
ICT	36%	15.5%
Nanotech	1.1%	18%
Biotech	5.8%	5.5%

Source: On basis of OECD, Compendium of Patent Statistics, 2008. Note: Renewables: wind (28.8 percent), solar (29.2 percent), geothermal (28 percent), ocean (7.6 percent), biomass (4.8 percent), waste (26.7 percent).

Figure 1: Countries' share of and specialisation in environmental patents



Source: WIPO 2009, Patent Cooperation Treaty applications relating to environmental technologies (2001-2005 average). Note: RTA is share of the country in world environmental patents relative to the share of the country in total world patents; RTA > 1 measures specialisation in environmental patents.

Table 2: EGD R&D expenditures, selected countries and regions

	Growth in R&D average annual growth rate, 2000-03	Share of country in total world EGD R&D, 2000-04	Share of country in EGD R&D relative to share of country in total R&D (RTA)
US	-2.5%	6.8%	0.15
Japan	-2.7%	27.9%	1.55
EU	-2.8%	46.5%	1.69
Germany	0.6%	3.8%	0.42
France	-0.3%	21.3%	2.07
UK	-27.8%	7.6%	1.05
Spain	31.1%	3.4%	3.20
Sweden	15.2%	1.9%	1.05

Source: OECD, ANBERD (2007). Note: The Spanish increase reverses the downward trend seen from 1995-2000; the Swedish trend was downwards between 1992-2001.

Source : Aghion, Veugelers, Serre (2009), Cold start for the green innovation machine,

Bruegel Policy Contribution, n°12, Novembre 2009, available on www.bruegel.org/publications/show.html

It is important to point out that recent and meaningful efforts have been recently made to promote environmental innovation, mainly under the pressure of public spending. On the figures 2.1 and 2.2, it can be observed an impressive surge of theses spending, which rise from 3 Billion dollars at the beginning of the 2000's to 8 billion in 2009 for the whole members of the IAE.

The same trends concern the Clean Energy Patents, which know an impressive increase over the last years, compared with its stagnation during the earlies 90's. The leading country in this field remains Japan (29,7%), followed by the USA (15,9%), and Germany (15,2%).

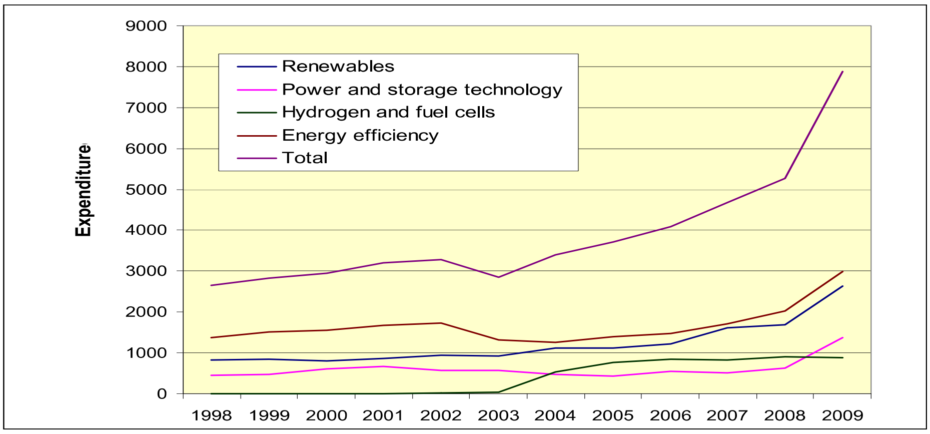


Figure 2.1 **Total IEA Government expenditures on relevant energy technology R&D** (million 2009 USD PPP)

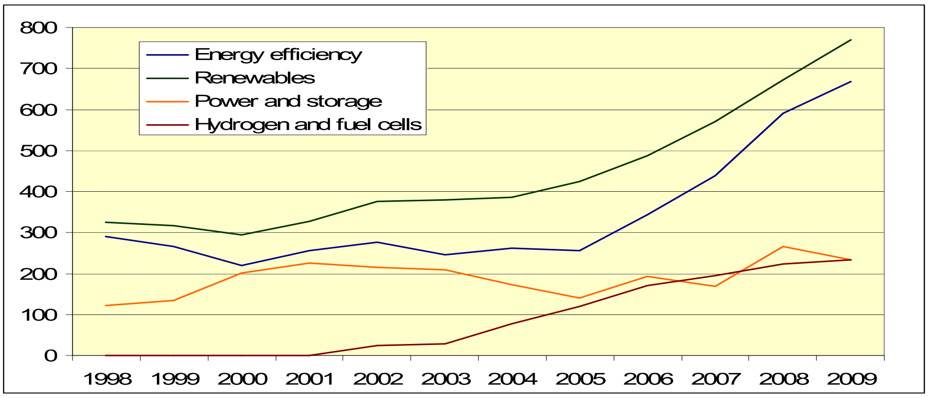


Figure 2.2 **Total European Government expenditures on relevant energy technology R&D (million 2009 USD PPP).**
Source: IEA, 2010

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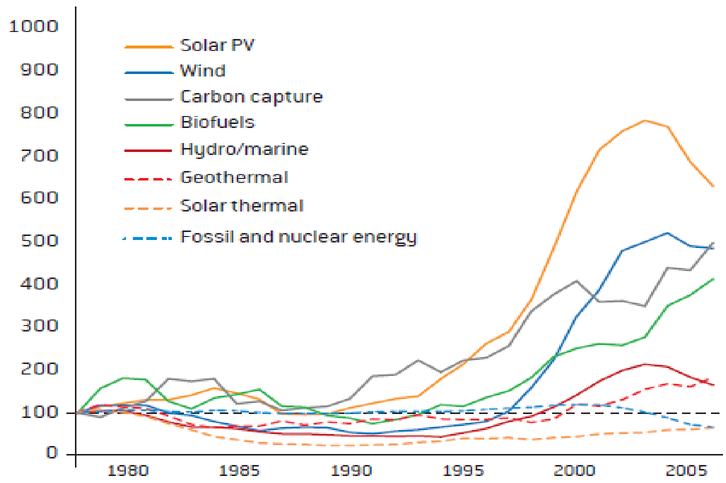


Figure 3 Clean Energy Patents, 1980-2005

Source: On the basis of UNEP/EPO/ICTSD, 2010, Patents and clean energy: bridging the gap between evidence and policy, in R. Veugelers, Activating the clean Innovation Machine, KUL Paper, 2012.

It is important to point out that environmental innovation field is far larger than the innovation of the sole eco-industries. In fact a lot of economic sectors are investing in environnement innovation, without belonging strictly to the eco-industries. For example, industrial sectors like car producers or aeronautics, which have the most important budget in R&D, are devoting a rising part of them in improving their energy efficiency.

As a consequence, a more general definition of environmental innovation has been created. According to the EOCD Report "Measuring Environmental Innovation" (2007), "*Eco-innovation is the production, assimilation or exploitation of a product, production process, service, or a managerial tool that is new to the organization that develops or adopts, and which leads, at throughout its lifecycle, to reducing environmental risks, pollution and other negative impacts of resource use (including energy) compared to other relevant alternatives*" (Arundel and Kemp, 1998, Kemp and Pearson, 2007). It has led to add a new module to the CIS Innovation survey, which is not compulsory. Its content is composed of a complete set of questions on the nature of the environmental gains of innovation, on the channel through innovation arrived in the firm (adoption or creation), on the purpose of the innovation, and on its different enablers: regulations, innovation subsidies and aids, consumers demand and voluntary agreements. Even if this CIS survey didn't lead to a lot of applications, the results already obtained come to a rather convergent results. Namely, in Nederland, 60% of the innovation surveyed in the Dynamo Database have environmental effects (Arrundel, Kanerva and. Kemp, 2011) , while an exploitation of the CIS-VI in Flamish Begium proved that 46% of innovation where environmental according to the CIS Survey definition (Veugelers, 2012). Anyway, an evolution seems to be in progress toward a greening of Innovation, even if considerable discrepancies between countries should be revealed through the CIS Survey.

I.2 Environmental Innovation and Energy Transition.

In the field of energy transition, economic thinking is mainly focused on the way and means to turn the technological trajectories toward a more carbon neutral economy. We already saw that the spontaneous working of markets does'nt lead to a sufficient level of Research development spending. The most general models are using an endogeneous growth framework, with knowledge (positive) and environmental (negative) externalities. These last one are linked to the existence of a "dirty" sector, using fossils energy, and a "clean" sector, or "green", using renewable energies. (Acemoglu D., Aghion P., Bursztyn L., Hemous D., (2009), for a pedagogical presentation see Aghion, Veugelers, Serre, 2009). The model proves that if acting quickly, a moderate carbon tax and a high RD subsidy towards environmental innovation will allow realize an energy transition at a low cost, without depressing the economic growth. The limit of this kind of model is linked to the ad hoc value of their structure and results, as proved by Hourcade, Pottier and Espagne (2011). They are generaly calibrated with values considered as compatible with more applied models. Some progress is waited with the confrontation of theses theoretical models on empirical datas. (Pizer, Popp (2008))

More applied works comes to convergent results with agreggated models. One of the discussed issues is related to the choice to make in the energy transition, between the lengthening of fossil fuels energies and the jump towards renewable energies. Past technical improvement in the use of fossil fuels has proved not to reduce the overall energy consumption, coming to a "rebound effect": as the rise in energy efficiency allows to sustain a high growth rate of productivity, the energy consumption can continue to rise, and fossil fuel to be used. And this situation could lead to divert investment to renewable energies. Near term policies can counteract with the objectives of long term policies, or according to Azar and Sanden « *There is a risk that the society in its quest for cost-minimizing in meeting near-term emissions targets, becomes blindfolded when it comes to the more difficult, but equally important issue of bringing more advanced technologies to the shelf* » (Azar et Sanden, 2005). In other words encouraging the use of technologies "on the shelf" to reach short-term emission reductions may lead to lock in the use of fossil fuels technologies, which won't be able to reduce more dramatically emissions.

Another feature of the energy transition is that it involves changes in sectors that require large long terms investments from mainly private companies. One could think that the enforcement of new environmental standards and of the cap and trade system should have lead to a renewing of the whole existing plants. But as stated before, it hasn't be the case: on the contrary an ageing of the existing power plant stock occurred in the USA over he last thirty years (W. Blyth, 2010), explained for a part by the implementation of environmental standards (Ellerman, 1996), and for another to the energy sector liberalization, which has dramaticaly reduced the profitability of the power plant sector. This “energy paradox” (Jaffe et Stavins, 1994, Mulder, de Groot et Hofkes, 2003), can explain the slowness of the diffusion of new energy technologies: the burden of investments and the perspectives of future technological improvement has led the companies to postpone their renewment investment. They instead prefered to modernise and refurbished their old equipment rather than renew them. Environmental regulations play an ambiguous role: as they increase the cost of changing completely old plants, they push the entreprises to modernize them by retrofitting their current machines vintages. In fact there is a substitution between the improvement of the working of the installed equipement and their replacement, and a complementarity between their different generations: improvement gained in the use of the most recent machines generation (“learning by using ») can benefit to the whole stock of machines, which can in this way be conform to the new environmental standards. But in this case the investment devoted to the retrofitting of the equipment won’t be available, nor necessary, for the purchase of a brand new equipment stock.

One of the main limits on the energy transition is due to the lags necessary to launch these technologies, which justify their funding by a public financing. The following table gives an estimation of the time at which the renewable resources using techniques should be competitive with coal electrical generation: it shows that, if certain technologies are already competitive, for others this period is farther, going to 2025-30, and can even be unknown, as in the case of the Carbon Capture Storage techniques (CCS).

Table 2.1 **Year to reach competitiveness with coal electrical generation**

Energy type	Description	Year
Solar	CSP (concentrating solar power)	2015 – 2030, depending on region
Solar	Photovoltaic panels	2015 – 2020 in sunniest regions, 2035 in intermediate zones
Wind	Inshore	2010 (already competitive in best sites)
Wind	Offshore	Up to 2025, depending on location
Biodiesel (algae)	Using CO_2 stream from coal-fired electrical plants	2020 – 2025
CCS	Carbon capture and storage	?

Source: Kovacevic and Wesseler, 2010; Balagopal et al, 2010, Ummel and Wheeler, 2008

Source : Arundel, Kanerva et Kemp, (2011), pp.19-20

II Environmental Innovation and Economic policy

The public policies that aims at promoting environmental innovation use a large choice of tools: regulation, generally of type “ command and control », economic tools, as taxes and subsidies, or the creation of cap and trade schemes. From a normative point of view, as in the Tirole report (J. Tirole, 2009) or in the Kolev recent Bruegel report (Kolev and alii, 2012), to be economicaly efficient all theses instrument should lead to a unique price of avoided carbon, this price being a signal of the constraint linked to the limitation of greenhouse gas emission at the world, regional and national levels.

In reality things are pretty different. As policy tools are jointly used, some kind of inconstancy appears, a situation that seems to be unavoidable but limits the efficicency of environmental policy. First of all, regulations play a key role in the environment protection, with effects that are rather controversial. While Porter et Van der Linde (1995) argue that they help to promote the growth of firms rather than limiting their competivity, for most of the economists they are an imperfect mean of environment protection, mainly because their cost is not taken into account, and even known by the decision makers (Milliman et Prince, (1989), Palmer, Oates, Portney, (1995) for a global survey see Ambec, Cohen, Elgie, Lanoie (2011)). As they concern all the agents, whatever their depollution price, they can have a high collective cost. From this point of view taxation is a better solution. It is a more flexible toll, which gives a useful information on the depollution cost. Cap and trade systems can be also used, in this case the allocation of polluting rights can be increased or decreased according to the evolution of the price of the pollution source on the market. Generally Cap and Trade systems are considered as a flexible and efficient tool for reducing a polluting source. For example according to the Joskow report on the US sulphur dioxyd market, the implementation of a cap and trade system had reduced to an half the cost of the emission reduction, by comparison of the preceeding command and control system. (Joskow et alii, 2000, for a recent survey see Schamenlsee and Stavins (2013)). On the contrary the ETS European system obtained more mixed results, with a recent drop of carbon price that could discourage depolluting effort (Goulder (2013), Newel, Pizer et

Raimi (2013), Zachman (2013). Moreover Cap and Trade systems should be combined with a carbon taxe on diffuses sources of pollution. The European experience, as reviewed by Zachman (in Kolev and alii, 2012), shows that the use of these three instruments on different scope and scale in Europe has lead to large disparities in the price of avoided carbon, between countries and in the different use of energy. Theses disparities are prejucial, not only to the economic efficiency of the mitigation policy, but also from a distributive justice point of view.

The design of eco-innovation policies has also to take account of the characteristics of environmental innovation, according to a typology developed by Abernathy et Clarke (1985) and Dijk (2010), and used by Arrundel et alli in the report Inno Grips 2011 (Arrundel et alii, 2011). This typology is ranking innovation according two dimensions:

- at first, a dimension linked to the institutional practices and uses, which could be maintained or changed, by technological or preference change. It is the "demand pull" side of environmental innovation.

-second, a dimension linked to the level of technological change, which can be minor or major in the technological knowledge and competences. It is a "technological push" aspect of these innovations.

The interaction between these two dimensions leads to define four types of environmental innovations, namely in incremental, social, techno-fixe or transformative innovations. More precisely:

- **incremental innovations** give an improvement to an existing technology, withourt changind the current uses and habits.

- **social innovations** are linked to a change in the practices associated to a minor technical improvment.

- **techno-fixe innovations** cover radical technical changes, which can help to preserv existing uses and habits.

- at last **transformative innovations** correspond to the implementation of new technological systemsn, that lead to a dramatic change of techniques and uses. These innovations need a complete reshaping of networks and of all the practices and ways of life.

Table 4 A typology of Environmental Innovations

User, market & institutional practices	Minor	Major
Disrupt existing practices	**Social innovation** - Organised car-sharing - Integrated transit - Planning changes	**Transformative innovation** - Electrical transport system - Renewable-electric power supply
Sustain existing practices	**Incremental innovation** - improved windmills - Hybrid vehicles - Low energy appliances - Passive housing - Concentrating solar power	**Techno-fixes** - Carbon capture & storage - Hydrogen cars - Biofuels - Geothermal power

Change in technological knowledge & competences

Source : Arundel A., Kanerva M., Kemp R., 2011, p.89

It is clear that the contemporary energy transition will mobilize a large portfolio of technologies that will take each of these four modes, according to a gradation depending on the interest of the different stakholders. While some expect that the technical progress can preserve the current way of life, others think that a radical change in way of life and practices could be sufficient to realize these energy transitions, which should be rather irrealisitic if some technological innovations, even minor, don't happen. This typology is also a useful tool to design and implement eco-innovation policies, as argued by Kemp (Kemp, 2011).

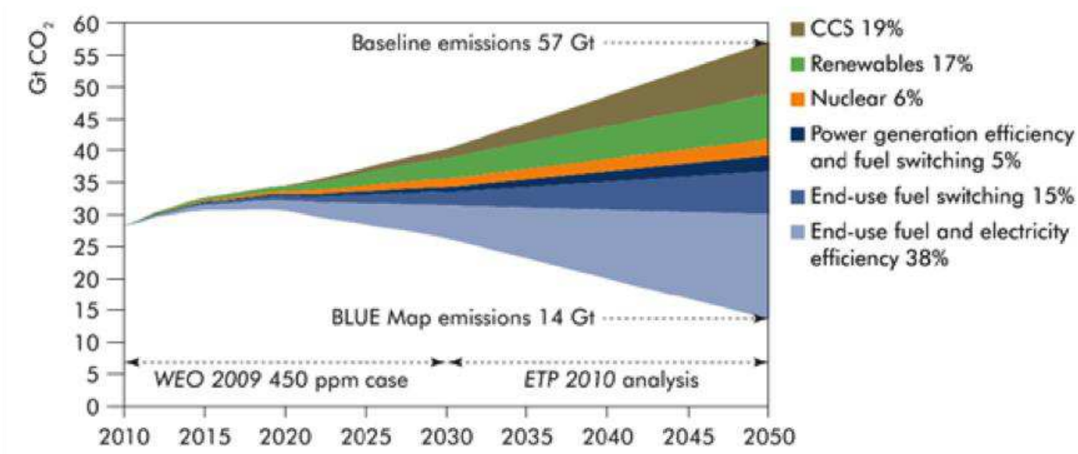
III CCS and BCCS, the ultimate mitigation techniques for advanced and developing countries?

The technologies of Carbon Capture and Storage, using fossil fuels (CCS) or bioenergy (BCCS), are now considered as one of the instruments able to reach the target of greenhouse gas stabilization at the 2050 horizon. (GIEC, 2005), IEA (2008).(see figure..) But the implementation of these techniques is bounded by important technical, economic and regulatory sources of uncertainty.

III.1 The economic conditions of the CCS feasibility

Although a new and recent mitigation technology, CCS is already implemented all over the world on several different pilot sites, and this deployment will continue in the coming years (see table 5). Once applied as an Enhanced Oil Recovery (EOR) technique on depleted oil fields, it may be used on other deep geological formations in order store carbon coming from a big source, generally a coal or gas-fired power unit plant. According to converging sources (RECIPE Report, 2009, IEA (2008)), CCS should come to commercial applications between the 2020 and 2030 years.

Figure 4 Key technologies for reducing CO2 emisisons under the IEA Blue Map Scenario



Source: Energy Technologies Perpsectives, 2010, IEA

If we use the preceding typology, CCS belongs clearly to the "ecofixes" technologies, which aim to preserv the use of fossil fuels, in allowing them to reduce their greenhouse gas emissions. While pilot sources are developed all over the world, the main promoters of CCS are countries using fosil fuels on a large scale which most of them refused, as USA, or are not bound as the non-Annexe 1 countries of the Kyoto protocol, to Geenhouse Gas (GHG) reduction targets. An exception is given by Scandinavian countries, which are leader in this field despite their large use of bioenergy. They are the promoters of BCCS, or Carbon Capture and Storage from Bioenergy, a technique that grafts CCS on a plant of biofuel production, or a biomass power plant unit (Möllersten et alii, 2003, 2006). As the production of biofuel is supposed to have a neutral carbon (or a zero carbon emission) life cycle, BCCS can lead to a negative carbon emission, in another words it could create an artidfical carbon pit. BCCS is mainly considered in the scenario of a sharp reduction of greenhouse gas to the level of 450 ppm in 2050 (instead of 550 Ppm in the central scenaraion of the IPCC report). Another justification of the development of this new technique lies in the fact that it will allow to compensate the small source of CO_2 emission, like housing or transport on which CCS can't be applied (Azar et alii, 2010). BCCS has been studied on various kind of bioenergy. An application of BCCS on a sugar beet unit in France has been studied in a project headed by the BRGM and the Labraotry o f Econolics of Orléans (Bonijoly et alii, 2009).

CCS and BCCS are subject to multiple sources of uncertainty: first, their economic fesability is linked to the carbon price, and to a regulatory framework, which is still missing, or depending on national regulation and of international climate negociations (Abadie et Chamorro (2008). Moreover the implementation of these techniques raises the problem of their acceptability. A recent survey on the acceptability studies of Campos and alii (Campos, Minh Ha-Duong, Merad, 2010) proved that theses techniques are generaly accepted by the neigbouring population, under the condition of a complet and transparent information of this population, which will be difficult to realize on the future sites.

Major active and planned large-scale CCS projects commencing before 2015 in Norway, the Netherlands, United States, Canada and Australia (sources: ETP ZEP, 2008; NETL, 2008; CO2CRC, 2009; NrCan, 2009; IEA GHG, 2009; MIT, 2009).

Country	Name (location)	Project leader	Reservoir type	CO_2 source	Size (Mt/year)	Start
Norway	Sleipner	StatoilHydro	Saline	Gas processing	1	1996
Norway	Snøhvit	StatoilHydro	Gas	LNG production	0.7	2008
Norway	Husnes	Sargas	EOR	Coal – post combustion	2.6	2011
Norway	Karstø	Naturkraft	Saline	Gas – post combustion	1.2	2012
Norway	Mongstad	StatoilHydro	Saline	Gas – post combustion	1.5	2014
Netherlands	CGEN	CGEN NV	Oil & gas	Coal – pre combustion	2	2014
Netherlands	Magnum	NUON	Oil & gas	Various – pre combustion	±1	2015
Netherlands	Enecogen	Eneco	Oil & gas	Gas – post combustion	2	2015
Netherlands	Maasvlakte	EON	Oil & gas	Coal – post combustion	±5	2015
Canada	Weyburn	Pan Canadian	EOR	Coal gasification	1	2000
Canada	Fort Nelson	PCOR	Saline	Gas processing	1.6	2011
Canada	BoundaryDam	SaskPower	EOR	Coal – oxy combustion	±1	2015
Canada	Genesee	Epcor	Saline	Coal – pre combustion	±1	2015
Canada	Alberta Carbon Trunk Line	Enhance Energy	EOR	Oil sand upgrading	1.8	2015
Canada	Quest	Shell	EOR	Oil sand upgrading	±1.5	2015
US	Mt Simon	MGSC/MRCSP	Saline	Ethanol production	1	2009
US	Gulf Coast	SEACARB	Saline	Gas processing	1	2009
US	Entrada	SWP	Saline	Gas processing	1.1	2010
US	Oologah	AEL/Alstom	EOR	Coal – post combustion	1.5	2011
US	Antelope	Basin Electric	EOR	Coal – post combustion	1	2012
US	WA Parish	NRG Energy	EOR	Coal – post combustion	1	2012
US	Williston	PCOR	EOR	Lignite – post combustion	1	2012
US	Kimberlina	CES	Saline	Coal – oxy combustion	1	2012
US	Kern County	Hydrogen Energy	EOR	Petcoke – post combustion	2	2014
US	West Wyoming	BigSky	Saline	Gas processing	1.5	2011
Australia	Coolimba	Aviva Corp.	Oil & gas	Coal – post combustion	3	2015
Australia	Moomba	Santos	EOR	Gas processing	1	2010
Australia	Zerogen	Stanwell	Saline	Coal – pre combustion	0.5	2012
Australia	Gorgon	Chevron Texaco	Saline	Gas processing	3.3	2013
Australia	Monash CTL Project	Monash Energy	Oil & Gas	Coal to liquids – separation	13	2015

Table 5 Active Sites of Carbon Capture and Storage in Norway, Sweden, Nederland, USA, Canada and Australia.

Source : Van Alphen, Hekkert, Turkenburg, 2010.

The technological constraints limiting the CCS deployment are heavy. First of all, several alternative techniques exist, which can be considered as an advantage but will lead to a duplication of the R&D spendings between the different techniques (Rai et alii, 2009). On another hand it is necessary to preserve a certain variety of technologies in order to avoid some kind of technological lock-in that appeared in some other technologies (Azar et Sande, 2008). These techniques are also subject to the energy paradox, namely that it will be probably better for the energy producer to retrofit their current technologies rather than install brand-new costlier equipement. In this kind of situation investors are facing a tradeoff between an immediate investment and its postponing; delaying an irreversible investment can be an optimal strategy because it allows to benefit for more information on a new technique and a market in process, at the risk of being overtaken by more audacious competitors, which will the be able to impose their own technological standard. But commiting too fastly in a way may means to support high level R&D spendings, to be copied by followers, and event to be driven into technological dead-ends.

Another point is linked to the existence of learning curves. Most of prospective studies in this field assume that will costs will fall down dramatically in the future thanks to learning effects. But a comparative study driven on three equivalent techniques, the liquefied natural gas (LNG), the nuclear energy, and the defulrization techniques in the US power plant sector, taught that this decrease in the costs has been proved for only two of theses techniques, (the two first) (Rai et alii, 2009). Moreover, this decrease is more largely due to the change in competition rather than a learning process. As CCS is still an infant technology that requires heavy investments, the use of learning curves seems to be rather optimistic.

Another crucial point lies in the dimension of sites. The commercial exploitation of CCS requires highly dimensioned plants, which will probably need network investment in order to pool different emissions sources. More generally, CCS as a general purpose technology will be confronted to the problem of the sharing of its financing between differents stakholders, mainly on the step of the CO_2 transport and storage.

Lastly, these techniques, though benefiting of private and public supports that allow to increase significantly the number of pilot sites all over the world, will be confronted to the crossing of the “valley of death” of Innovation. In the equivalent industries quoted before, this crossing has required the use of the complete set of support instruments, namely: investment and feed-in price subsidies, and creation of regulation protecting operator and guaranteeing their long term feasibiliy (Raii et alii, op.cit.). The timing of these measure will play a crucial role: before imposing constraining regulations, investment in demonstration units should be subsidied, then the production itself on a long term horizon (Finon, 2009).

Technical Development Step	Demonstrator on a commercial scale 2015-20	Post demonstration 2020-30	Pre-commercial 2030-45
Regulatory Obligation			Yes
Investment Subsidy	Yes	Yes	
Production Subsidy		Yes	Yes

Source : D. Finon (2009), Efficiency of Policy choice for the deployment of large scale low carbon technologies, the case of CCS, GIS- Larsen, November 2009.

A recent study (Van Alphen, Hekkert, Turkenburg, (2010)) has been driven to evaluate the CCS techniques as a technical Innovation system. It aims at evaluate the quality of the technical innovation system using interviews with 100 persons, involved in this technology. Seven aspects were documented, according to the methodology of the Inno Grips Scoreboard:, knowledge development and diffusion, guidance, market formation, resource mobilization, creation of legitimacy and entrepreneurial activities. If the indicators on the first items are rather high (knowledge diffusion and knowledge, guidance), the scores reached on both demand, supply and resources are rather low, as for the creation of legitimacy results.

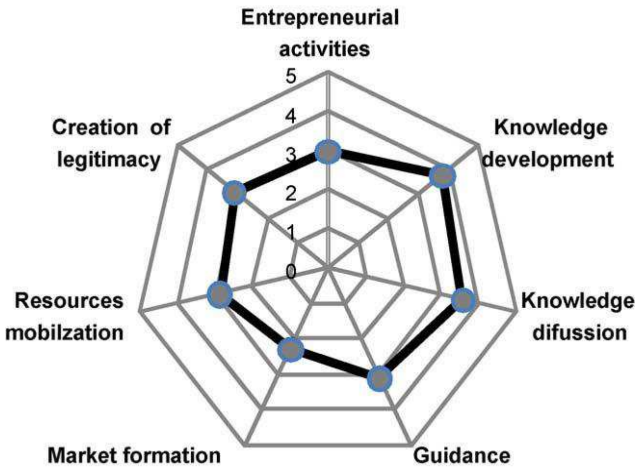


Fig. 1. Spider diagram depicting the overall score on the functions of innovation systems by a hundred experts in Norway, Netherlands, United States, Canada and Australia.

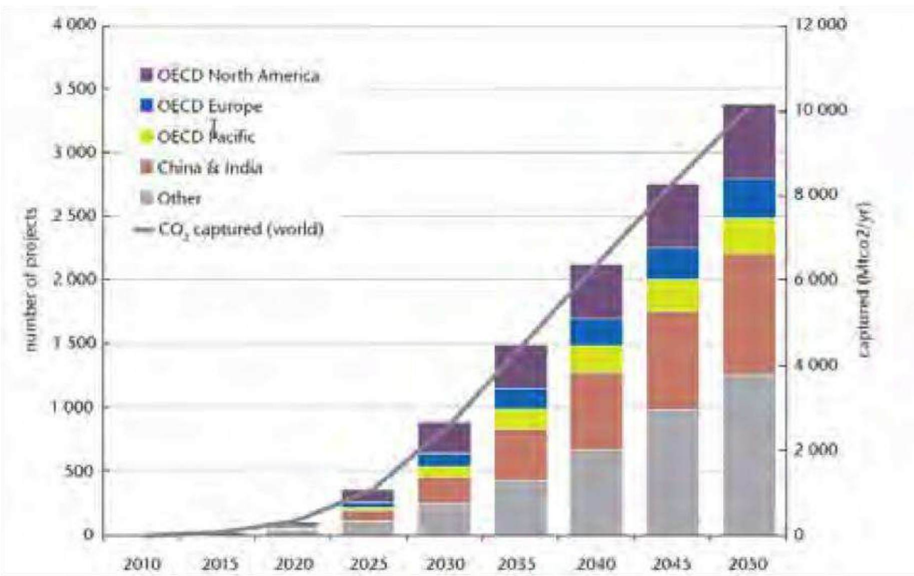
Figure 5 The CCS score as an Innovation system

Source: Van Alphen, Hekkert, Turkenburg, 2010.

III.2 How to implement CCS in developing countries ?

As other environmental innovations, the roadmap of CCS deployment should begin with the industrialized countries, and to continue in the developing countries. As the energy mix of most of them, especially China and India, is largely depending on fossil fuels, it leaves a large field for the CCS deployment. For example the AIE report on CCS expects an increasing share of CCS in developing countries, alongside of their greenhouse gas emissions. It should offset that of OECD countries around 2030. As these countries of the non Annexe 1 of the Kyoto Agreement are not bound to a target of decrease of their GHG emissions, developing countries does'nt have any incentives to implement it. IEA is forecasting an increasing part of CCS installed in thses countries, especially in China, India, and in others developing countries in its Blue Map Scenarion which could be compatible with a rise of less than 2° in 2050. It is not surprising if we know that China and India are already respectively the first and third users of coal over the world, with a part of more than 60% of their energy mix devoted to this energy source.

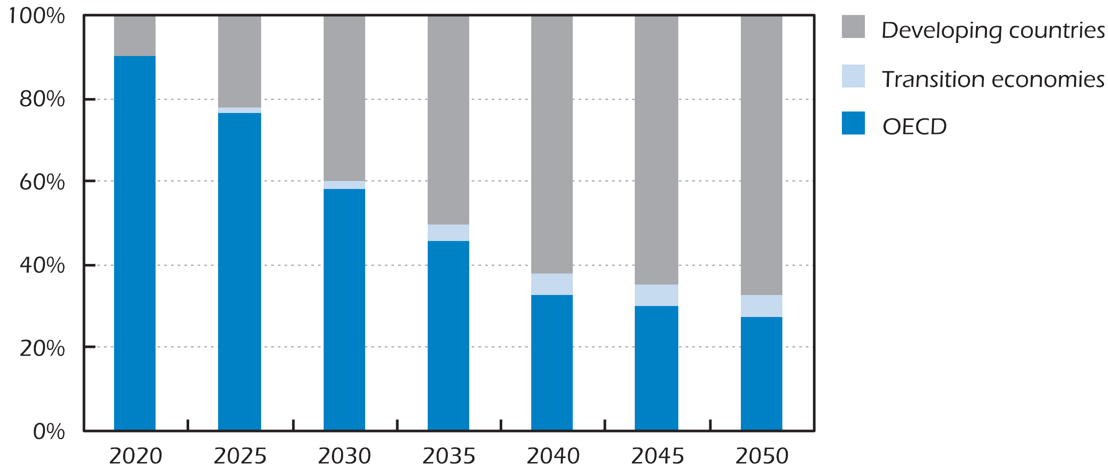
Figure 6. Global CCS project deployment- IEA Blue Map Scenario



Source: IEA Greenhouse Gas R&D program Annual Review 2011

A meaningful progress has been realized recently with the inclusion of CCS in CDM project. It will allow industrialized countries to finance CCS project in developing countries. A first project is already planned in Vietnam, the White Tiger Field Project (Nguyen, Min Ha and Hoang, 2011), that could become the first commercial project in Asia. All these CDM projects are nonetheless depending on the avoided carbon price, which is still high. By the time being the overall cost of captutre, transport and storage is at the best between 30 and 60€ a ton, far higher than its price on the ETS cap and trade european market and of other cap and trade markets.

Figure 7 Global CCS Deployment-IEA Blue Map Scenario



Source: IEA, 2008 (ETP Model).

Moreover, the recent shift in the allowances of MDP, which aims to divert them from China and other emerging countries to less advanced countries, could another obstacle to the CCS deployment in China under this framework. Anyway, as the China example proved it, these countries are expecting to implement this technique, according to a roadmap that which doesn't raise the question of it financing.

Figure 8 The China Coal Research Institute Technology Roadmap for CCS

Task	2010	2020	2030	2040	2050
CO_2 capture	Dissemination of capture technologies for low-concentration CO_2 and cost reduction				
	Demonstration and dissemination of oxygen-rich combustion technologies and cost reduction				
Decarburisation to produce hydrogen	Demonstration of coal-based hydrogen production		Commercialisation of coal-based hydrogen production		Provision of hydrogen energy, including pipelines and hydrogen stations
CO_2 transport	Technical and economic feasibility	Application of CO_2 storage and transport			
CO_2 storage	Research and geological investigation of storage potential	Demonstration and verification	CO_2 capture-transport-storage monitoring plan		

Sources: IEA (forth coming); Cleaner Coal in China; OECD/IEA, Paris.

Source: IEA Report on CCS, 2008.

IV CONCLUSION

Environmental Innovation, highly desired and encouraged, is difficult to implement and promote from a normative or an empirical point of view, especially when applied to energetic transitions. The main reason explaining this situation lays in the difficulty to shift the market mechanisms towards a more decarbonized economy, especially in emetting credible price-signals. While advanced countries are implementing these techniques at very different paces, developing countries could benefit from their experience but will neeed a financial support from the more advanced countries. To reach this goal it is necessary to define credible national and international policies, coming to clong term commitments and steady regulatory schemes. The agenda of the implementation of these techniques is also an important stake, in order to avoid technological lock-in due to inconsistent or short-term incentive schemes. It is that conditions that will allow new innovation system turned to a more neutral carbon economy.

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